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Specification and Drawings as originally filed, with Application for Patent Serial No: **2,331,229**, on January 17, 2001, by **CATENA NETWORKS CANADA INC.**, assignee of Bin Li and Andrew Deczky, for "System and Method for Net Coding Gain of Turbo TCM in Non -flat SNR Channels".

Agent certificateur/Certifying Officer

January 14, 2002

Date

TITLE: G.gen: G.dmt.bis: G.lite.bis: : Net Coding Gain Evaluation of Turbo TCM (BI-090R1) in Non-flat SNR Channels

ABSTRACT

This contribution is to evaluate the net coding gain of a turbo TCM proposed in BI-090R1[1] in the non-flat SNR channels specified in BI-116[2]. The simulation results show that the BI-090R1 turbo TCM can provide good performance of large net coding gain over uncoded schemes in the non-flat SNR channels. Also this turbo TCM has very low implementation complexity relatively to the other turbo TCM schemes presented so far.

1. Introduction:

This contribution is to evaluate the net coding gain of the turbo TCM proposed in BI-090R1[1] in the non-flat SNR channels specified in BI-116[2]. The bit error rate performances of this turbo TCM are evaluated through computer simulations for AWGN channel with non-flat SNR in the sub-carriers. The coding gains are presented for both cases with and without concatenation of RS codes. The simulation results show that the BI-090R1 turbo TCM can provide good performance of large net coding gain over uncoded schemes in the non-flat SNR channels. Also this turbo TCM has very low implementation complexity relatively to the other turbo TCM schemes.

2. Turbo TCM:

Fig. 1 shows the block diagram of the BI-090R1 turbo TCM [1]. The mapping is the concatenated Gray mapping on I&Q axis independently [1]. The detail puncturing pattern and puncturing rate of turbo encoder is shown in tables 1-13.

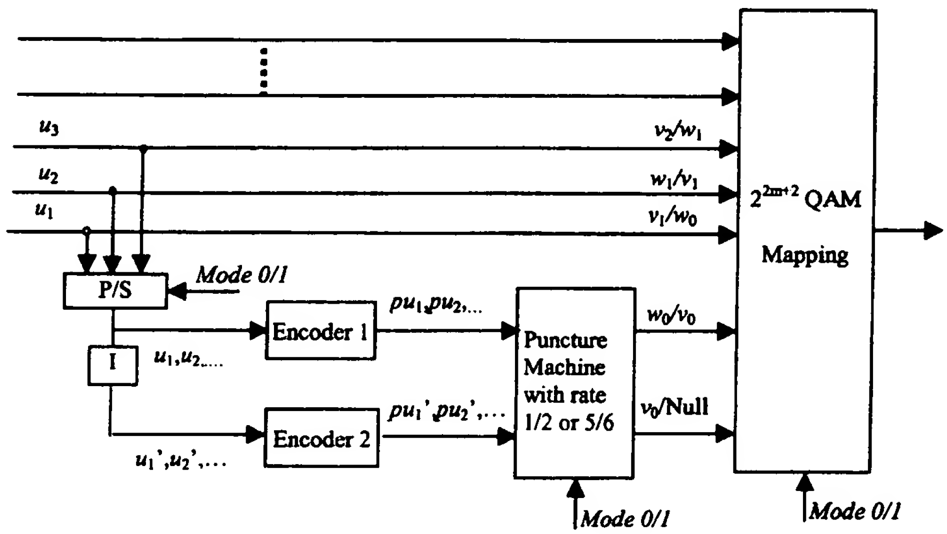

Fig. 1 the block diagram of the BI-090R1 turbo TCM [1]

2.1 Transmit 1 bit using 4QAM with rate 1/2

TABLE 1. Puncturing and Mapping for 4QAM with rate 1/2

Information data d_k	d_1, d_2	
Encoder input data	d_1	d_2
Parity bit from encoder 1	p_1	-
Parity bit from encoder 2	-	p_2
2ASK symbol (I)	d_1	d_2
2ASK symbol (Q)	p_1	p_2
4QAM	(d_1, p_1)	(d_2, p_2)

2.2 Transmit 2 bits using 16QAM with rate 2/4

TABLE 2. Puncturing and Mapping for 16QAM with rate 2/4

Information data d_k	d_1, d_2	
Encoder input data	d_1	d_2
Parity bit from encoder 1	p_1	-
Parity bit from encoder 2	-	p_2
4ASK symbol (I)	(d_1, p_1)	
4ASK symbol (Q)	(d_2, p_2)	
16QAM	(d_1, p_1, d_2, p_2)	

2.3 Transmit 4 bits using 64QAM with rate 4/6

TABLE 3. Puncturing and Mapping for 64QAM with rate 4/6

Information data d_k	d_1, d_2, d_3, d_4 *	
Encoder input data	d_1	d_2
Parity bit from encoder 1	p_1	-
Parity bit from encoder 2	-	p_2
8ASK symbol (I)	(d_3, d_1, p_1)	
8ASK symbol (Q)	(d_4, d_2, p_2)	
64QAM	$(d_3, d_1, p_1, d_4, d_2, p_2)$	

***** d_3, d_4 **do not go through the convolutional encoder in order to reduce the decoder complexity.**

2.4 Transmit 6 bits using 256QAM with rate 6/8

TABLE 4. Puncturing and Mapping for 256QAM with rate 6/8

Information data d_k	$d_1, d_2, d_3, d_4, d_5, d_6$ *	
Encoder input data	d_1	d_2
Parity bit from encoder 1	p_1	-
Parity bit from encoder 2	-	p_2
16ASK symbol (I)	(d_5, d_3, d_1, p_1)	
16ASK symbol (Q)	(d_6, d_4, d_2, p_2)	
256QAM	$(d_5, d_3, d_1, p_1, d_6, d_4, d_2, p_2)$	

***** d_3, d_4, d_5, d_6 **do not go through the convolutional encoder in order to reduce the decoder complexity.**

2.5 Transmit 8 bits using 1024QAM with rate 8/10

TABLE 5. Puncturing and Mapping for 1024QAM with rate 8/10

Information data d_k	$d_1, d_2, d_3, d_4, d_5, d_6, d_7, d_8$ *	
Encoder input data	d_1	d_2
Parity bit from encoder 1	p_1	-
Parity bit from encoder 2	-	p_2
32ASK symbol (I)	$(d_7, d_5, d_3, d_1, p_1)$	
32ASK symbol (Q)	$(d_8, d_6, d_4, d_2, p_2)$	
1024QAM	$(d_7, d_5, d_3, d_1, p_1, d_8, d_6, d_4, d_2, p_2)$	

*** $d_3, d_4, \ldots, d_7, d_8$ do not go through the convolutional encoder in order to reduce the decoder complexity.**

2.6 Transmit 10 bits using 4096QAM with rate 10/12

TABLE 6. Puncturing and Mapping for 4096QAM with rate 10/12

Information data d_k	$d_1, d_2, d_3, d_4, d_5, d_6, d_7, d_8, d_9, d_{10}$ *	
Encoder input data	d_1	d_2
Parity bit from encoder 1	p_1	-
Parity bit from encoder 2	-	p_2
64ASK symbol (I)	$(d_9, d_7, d_5, d_3, d_1, p_1)$	
64ASK symbol (Q)	$(d_{10}, d_8, d_6, d_4, d_2, p_2)$	
4096QAM	$(d_9, d_7, d_5, d_3, d_1, p_1, d_{10}, d_8, d_6, d_4, d_2, p_2)$	

*** $d_3, d_4, \ldots, d_9, d_{10}$ do not go through the convolutional encoder in order to reduce the decoder complexity.**

2.7 Transmit 12 bits using 16384QAM with rate 12/14

TABLE 7. Puncturing and Mapping for 16384QAM with rate 12/14

Information data d_k	$d_1, d_2, d_3, d_4, d_5, d_6, d_7, d_8, d_9, d_{10}, d_{11}, d_{12}$*	
Encoder input data	d_1	d_2
Parity bit from encoder 1	p_1	-
Parity bit from encoder 2	-	p_2
128ASK symbol (I)	$(d_{11}, d_9, d_7, d_5, d_3, d_1, p_1)$	
128ASK symbol (Q)	$(d_{12}, d_{10}, d_8, d_6, d_4, d_2, p_2)$	
16384QAM	$(d_{11}, d_9, d_7, d_5, d_3, d_1, p_1, d_{12}, d_{10}, d_8, d_6, d_4, d_2, p_2)$	

*** $d_3, d_4, \ldots, d_{11}, d_{12}$ do not go through the convolutional encoder in order to reduce the decoder complexity.**

2.8 Transmit 3 bits using 16QAM with rate 3/4

TABLE 8. Puncturing and Mapping for 16QAM with rate 3/4

Information data d_k	$d_1, d_2, d_3, d_4, d_5, d_6$					
Encoder input data	d_1	d_2	d_3	d_4	d_5	d_6
Parity bit from encoder 1	-	p_2	-	-	-	-
Parity bit from encoder 2	-	-	-	-	p_5	-
4ASK symbol (I)	(d_1, d_2)			(d_4, d_5)		
4ASK symbol (Q)	(d_3, p_2)			(d_6, p_5)		
16QAM	(d_1, d_2, d_3, p_2)			(d_4, d_5, d_6, p_5)		

2.9 Transmit 5 bits using 64QAM with rate 5/6

TABLE 9. Puncturing and Mapping for 64QAM with rate 5/6

Information data d_k	$d_1, d_2, d_3, d_4, d_5, d_6, d_7, d_8, d_9, d_{10}$ *					
Encoder input data	d_1	d_2	d_3	d_4	d_5	d_6
Parity bit from encoder 1	-	p_2	-	-	-	-
Parity bit from encoder 2	-	-	-	-	p_5	-
8ASK symbol (I)	(d_7, d_1, d_2)			(d_9, d_4, d_5)		
8ASK symbol (Q)	(d_8, d_3, p_2)			(d_{10}, d_6, p_5)		
64QAM	$(d_7, d_1, d_2, d_8, d_3, p_2)$			$(d_9, d_4, d_5, d_{10}, d_6, p_5)$		

***** d_7, d_8, d_9, d_{10} **do not go through the convolutional encoder in order to reduce the decoder complexity.**

2.10 Transmit 7 bits using 256QAM with rate 7/8

TABLE 10. Puncturing and Mapping for 256QAM with rate 7/8

Information data d_k	$d_1, d_2, d_3, d_4, d_5, d_6, d_7, d_8, d_9, d_{10}, d_{11}, d_{12}, d_{13}, d_{14}$ *					
Encoder input data	d_1	d_2	d_3	d_4	d_5	d_6
Parity bit from encoder 1	-	p_2	-	-	-	-
Parity bit from encoder 2	-	-	-	-	p_5	-
16ASK symbol (I)	(d_{11}, d_7, d_1, d_2)			(d_{13}, d_9, d_4, d_5)		
16ASK symbol (Q)	(d_{12}, d_8, d_3, p_2)			$(d_{14}, d_{10}, d_6, p_5)$		
256QAM	$(d_{11}, d_7, d_1, d_2, d_{12}, d_8, d_3, p_2)$			$(d_{13}, d_9, d_4, d_5, d_{14}, d_{10}, d_6, p_5)$		

***** d_7, d_8, ..., d_{13}, d_{14} **do not go through the convolutional encoder in order to reduce the decoder complexity.**

2.11. Transmit 9 bits using 1024QAM with rate 9/10

TABLE 11. Puncturing and Mapping for 1024QAM with rate 9/10

Information data d_k	$d_1, d_2, d_3, d_4, d_5, d_6, d_7, d_8, d_9, d_{10}, \ldots, d_{17}, d_{18}$ *					
Encoder input data	d_1	d_2	d_3	d_4	d_5	d_6
Parity bit from encoder 1	-	p_2	-	-	-	-
Parity bit from encoder 2	-	-	-	-	p_5	-
32ASK symbol (I)	$(d_{15}, d_{11}, d_7, d_1, d_2)$			$(d_{17}, d_{13}, d_9, d_4, d_5)$		
32ASK symbol (Q)	$(d_{16}, d_{12}, d_8, d_3, p_2)$			$(d_{18}, d_{14}, d_{10}, d_6, p_5)$		
1024QAM	$(d_{15}, d_{11}, d_7, d_1, d_2, d_{16}, d_{12}, d_8, d_3, p_2)$			$(d_{17}, d_{13}, d_9, d_4, d_5, d_{18}, d_{14}, d_{10}, d_6, p_5)$		

***** $d_7, d_8, \ldots, d_{17}, d_{18}$ **do not go through the convolutional encoder in order to reduce the decoder complexity.**

2.12. Transmit 11 bit using 4096QAM with rate 11/12

TABLE 12. Puncturing and Mapping for 4096QAM with rate 11/12

Information data d_k	$d_1, d_2, d_3, d_4, d_5, d_6, d_7, d_8, d_9, d_{10}, \ldots, d_{21}, d_{22}$ *					
Encoder input data	d_1	d_2	d_3	d_4	d_5	d_6
Parity bit from encoder 1	-	p_2	-	-	-	-
Parity bit from encoder 2	-	-	-	-	p_5	-
64ASK symbol (I)	$(d_{19}, d_{15}, d_{11}, d_7, d_1, d_2)$			$(d_{21}, d_{17}, d_{13}, d_9, d_4, d_5)$		
64ASK symbol (Q)	$(d_{20}, d_{16}, d_{12}, d_8, d_3, p_2)$			$(d_{22}, d_{18}, d_{14}, d_{10}, d_6, p_5)$		
4096QAM	$(d_{19}, d_{15}, d_{11}, d_7, d_1, d_2, d_{20}, d_{16}, d_{12}, d_8, d_3, p_2)$			$(d_{21}, d_{17}, d_{13}, d_9, d_4, d_5, d_{22}, d_{18}, d_{14}, d_{10}, d_6, p_5)$		

***** $d_7, d_8, \ldots, d_{21}, d_{22}$ **do not go through the convolutional encoder in order to reduce the decoder complexity.**

2.13. Transmit 13 bits using 16384QAM with rate 13/14

TABLE 13. Puncturing and Mapping for 16384QAM with rate 13/14

Information data d_k	$d_1, d_2, d_3, d_4, d_5, d_6, d_7, d_8, d_9, d_{10}, \ldots, d_{25}, d_{26}$ *					
Encoder input data	d_1	d_2	d_3	d_4	d_5	d_6
Parity bit from encoder 1	-	p_2	-	-	-	-
Parity bit from encoder 2	-	-	-	-	p_5	-
128ASK symbol (I)	$(d_{23}, d_{19}, d_{15}, d_{11}, d_7, d_1, d_2)$			$(d_{25}, d_{21}, d_{17}, d_{13}, d_9, d_4, d_5)$		
128ASK symbol (Q)	$(d_{24}, d_{20}, d_{16}, d_{12}, d_8, d_3, p_2)$			$(d_{26}, d_{22}, d_{18}, d_{14}, d_{10}, d_6, p_5)$		
16384QAM	$(d_{23}, d_{19}, d_{15}, d_{11}, d_7, d_1, d_2, d_{24}, d_{20}, d_{16}, d_{12}, d_8, d_3, p_2)$			$(d_{25}, d_{21}, d_{17}, d_{13}, d_9, d_4, d_5, d_{26}, d_{22}, d_{18}, d_{14}, d_{10}, d_6, p_5)$		

***** $d_7, d_8, \ldots, d_{25}, d_{26}$ **do not go through the convolutional encoder in order to reduce the decoder complexity.**

3. Net Coding Gain in Non-flat SNR Channels:

3.1 Net Coding Gain in Medium Loop Channel

In this medium loop channel, it is assumed that there are 200 bins per DMT symbol and the SNR (in dB) at kth bin is

$$SNR(k) = SNR0 - SNR\_slope * k \qquad (1)$$

where $SNR0 = 50$ and $SNR\_slope = 50/200$. The bit allocation and gain control are used with the maximum gain (power) adjustment in each bin less than 2.5dB and the average gain (power) adjustment over active bins less than 0dB (i.e., no overall power boost). The uncoded schemes and the turbo TCM transmit the same information data rate.

Figure 2 shows the net coding gain of the turbo TCM scheme over uncoded scheme with the latency of 0.5ms (or one DMT symbol). The bit error rate is simulated at the SNR that is less than the reference SNR defined in (1) with the amount of SNR_backoff (in dB), i.e., $SNR\_sim(k) = SNR0 - SNR\_backoff - SNR\_slope * k$. Since the latency is 0.5ms or one DMT symbol, the turbo interleaver size is very small of 380bits. The turbo TCM coding gain without RS code compared with uncoded scheme is about 5.8dB at the BER of 10^{-7}. But with RS code, the overall coding gain can achieve 7.0dB.

Figure 3 shows the net coding gain of the turbo TCM scheme over uncoded scheme with the latency of 10ms (or 20 DMT symbols). The bit error rate is simulated at the SNR that is less than the reference SNR defined in (1) with the amount of SNR_backoff (in dB), i.e., $SNR\_sim(k) = SNR0 - SNR\_backoff - SNR\_slope * k$. Since the latency is 10ms or 20 DMT symbols, the turbo interleaver size is very large of 7600bits. The turbo TCM coding gain without RS code compared with uncoded scheme is about 6.5dB at the BER of 10^{-7}. With RS code, the overall coding gain can achieve 7.7dB.

3.2 Net Coding Gain in long Loop Channel

In this long loop channel, it is assumed that there are 100 bins per DMT symbol and the SNR (in dB) at kth bin is

$$SNR(k) = SNR0 - SNR\_slope * k \qquad (2)$$

where $SNR0 = 35$ and $SNR\_slope = 35/100$. The bit allocation and gain control are used with the maximum gain (power) adjustment in each bin less than 2.5dB and the average gain (power) adjustment over active bins less than 0dB (i.e., no overall power boost). The uncoded schemes and the turbo TCM schemes transmit the same information data rate.

Figure 4 shows the net coding gain of the turbo TCM scheme over uncoded scheme with the latency of 0.5ms (or one DMT symbol). The bit error rate is simulated at the SNR that is less than the reference SNR defined in (2) with the amount of SNR_backoff (in dB), i.e., $SNR\_sim(k) = SNR0 - SNR\_backoff - SNR\_slope * k$. Since the latency is 0.5ms or one DMT symbol, the turbo interleaver size is very small of 159bits. The turbo TCM coding gain without RS code compared with uncoded scheme is about 4.5dB at the BER of 10^{-7}. But with RS code, the overall coding gain can achieve 6.2dB.

Figure 5 shows the net coding gain of the turbo TCM scheme over uncoded scheme with the latency of 10ms (or 20 DMT symbols). The bit error rate is simulated at the SNR that is less than the reference SNR defined in (2) with the amount of SNR_backoff (in dB), i.e., $SNR\_sim(k) = SNR0 - SNR\_backoff - SNR\_slope * k$. Since the latency is 10ms or 20 DMT symbols, the turbo interleaver size is very large of 3200bits. The turbo TCM coding gain without RS code compared with uncoded scheme is about 6.4dB at the BER of 10^{-7}. With RS, the overall coding gain can achieve 7.8dB.

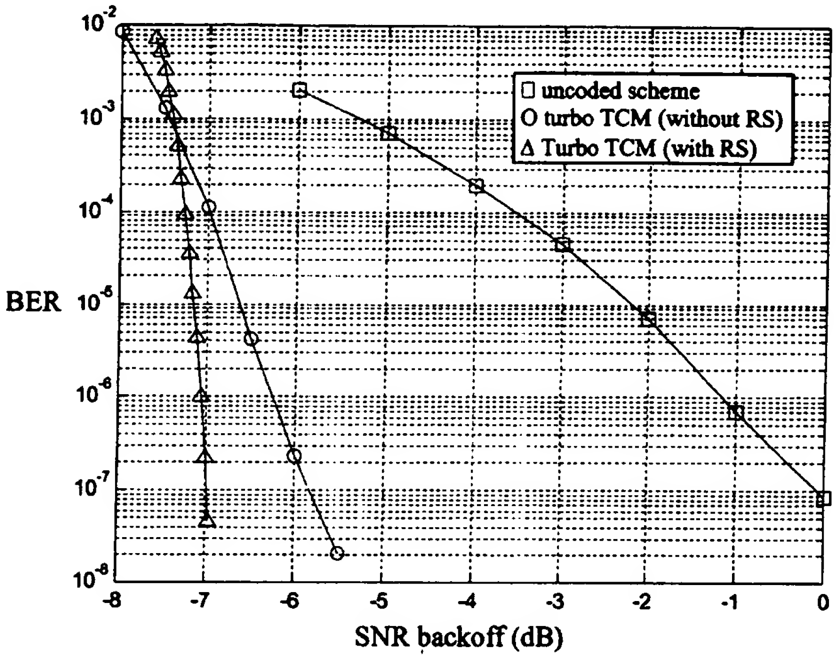

Figure 2. The BER performance of low latency of 0.5ms for medium loop.

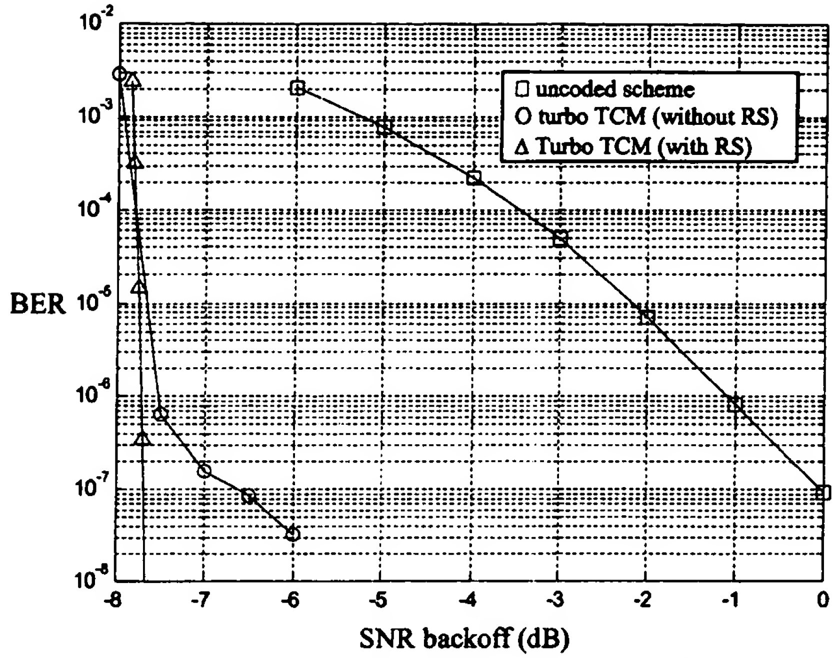

Figure 3. The BER performance of high latency of 10ms for medium loop.

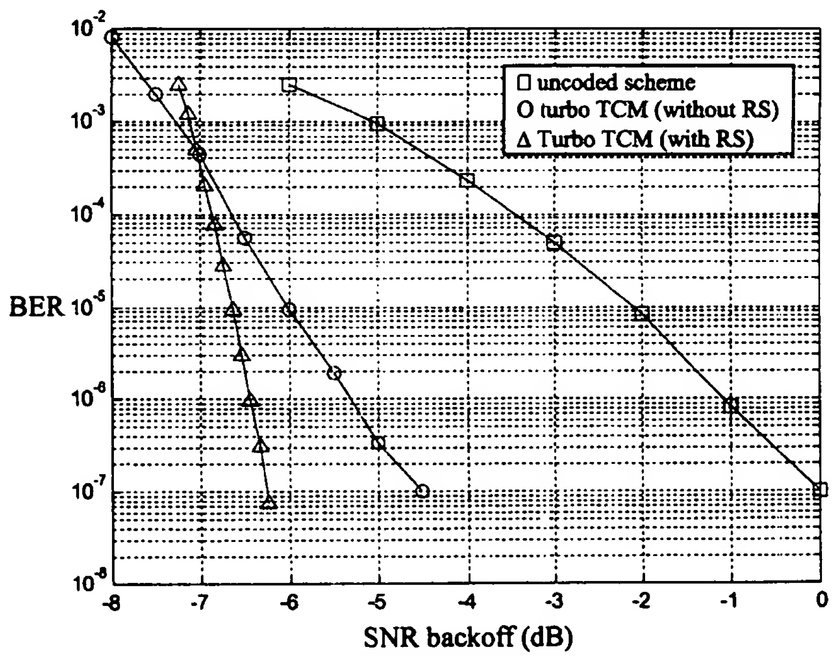

Figure 4. The BER performance of low latency of 0.5ms for long loop.

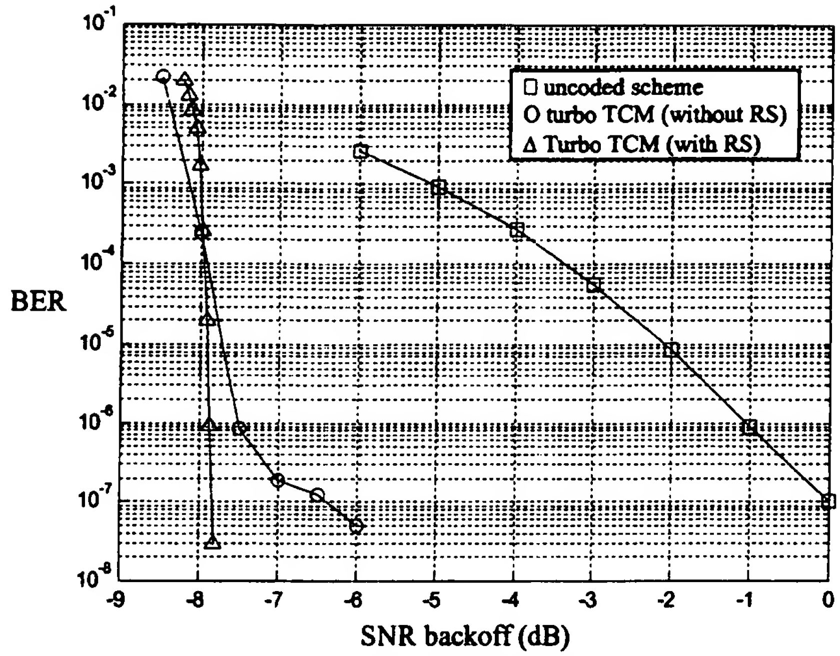

Figure 5. The BER performance of high latency of 10ms for long loop.

4. Summary and Conclusions:

Table 14 is the summary of the net coding gain of our turbo TCM over uncoded schemes in the non-flat SNR channels. For the low latency of 0.5ms, the coding gain without RS code is about 4.5dB for long loop and 5.8dB for medium loop because of the very short turbo interleaver size. The overall coding gain of turbo TCM plus RS code can achieve 6.2dB for the long loop and 7.0dB for the medium loop. But for the high latency of 10ms, the coding gain of turbo TCM alone can achieve about 6.4dB over the uncoded scheme. The overall coding gain of turbo TCM plus RS code can achieve about 7.7dB.

Table 14. Net Coding Gain (at the BER of 10^{-7}) of Turbo TCM in the non-flat SNR channels.

	Latency	# of symbols	Interleaver size	Coding gain[1]	Coding gain[2]
Medium Loop	0.5ms	1	380bits	5.8dB	7.0dB
	10ms	20	7600bits	6.5dB	7.7dB
Long Loop	0.5ms	1	159bits	4.5dB	6.2dB
	10ms	20	3200bits	6.4dB	7.8dB

Coding gain[1] --- coding gain without RS code. Coding gain[2] --- coding gain with RS code.

This contribution is to evaluate the net coding gain of the turbo TCM proposed in BI-090R1 in the non-flat SNR channels specified in BI-116. The simulation results show that the BI-090R1 turbo TCM can provide good performance of large net coding gain over uncoded schemes in the non-flat SNR channels. Also this turbo TCM has very low implementation complexity relatively to the other turbo TCM schemes.

References:

[1] "A Turbo TCM Scheme with Low Decoding Complexity", ITU standard contribution, BI-090R1, Bangalore, India, October 23-27, 2000.

[2] "Proposal for Evaluation of Net Coding Gain on a Channel with Non-flat SNR", ITU standard contribution, BI-116, Bangalore, India, October 23-27, 2000.

[3] "Report of the Ad Hoc on Improved Coding Gain", ITU standard contribution, BI-110, Bangalore, India, October 23-27, 2000.

[4] "Performance Simulation Results on Turbo Coding", ITU standard contribution, NT-112, Nashville, USA, November 1999.

[5] "Performance Evaluation of Proposed TTCM (PCCC) with R-S Code and without R-S Code", ITU standard contribution, D.748(WP1/15), Geneva, April 2000.

[6] "Proposal and Performance Evaluation of TTCM (PCCC) with R-S Code", ITU standard contribution, FI-122, Fiji Island, Feb. 2000.

[7] "New Proposal of Turbo Codes for ADSL Modem", ITU standard contribution, BA-020, Antwerp, Belgium, June 2000.

[8] "Performance Evaluation of Proposed TTCM with R-S and without R-S Code", ITU standard contribution, HC-048R1, Huntsville, Canada, July 31-August 4, 2000.

[9] "Results of the Requirements Required in the Coding Ad Hoc Report (BA-108R1) for the Proposed Turbo Codes for ADSL Modem by Vocal Technologies Ltd in BA-020R1", ITU standard contribution, HC073, Huntsville, Canada, July 31-August 4, 2000.

[10] "Proposal for Inner-interleaver of TTCM(PCCC)", ITU standard contribution, BA-088R1, Antwerp, Belgium, June 19-23, 2000.

Turbo TCM Scheme using R=2/3 Recursive Convolutional Encoder for ADSL

The following uses coding rate R=2/3 recursive convolutional encoder in the above turbo TCM scheme [1] which was proposed in ITU ADSL standard meeting.

[1] Bin Li, Andrew Deczky, "A Turbo TCM Scheme with Very Low Decoding Complexity", ITU-T BI-90R1, Catena Networks, Babgalore, India, Oct. 23-27, 2000.

1. Recursive Convolutional Encoder with Coding Rate R=2/3

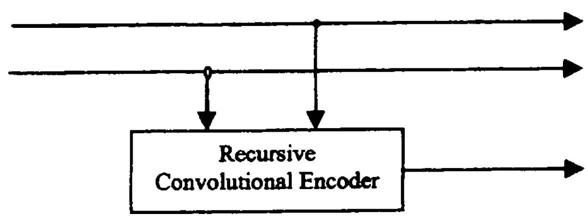

Figure 1(a). The recursive convolutional encoder with R=2/3.

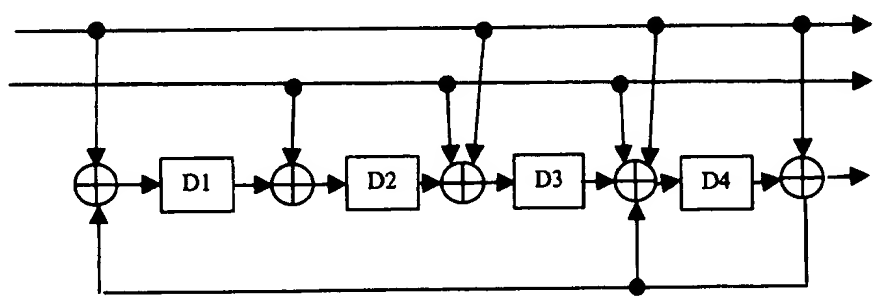

Figure 1(b). An example of the recursive convolutional encoder with R=2/3.

2. Turbo TCM Schemes using Recursive Convolutional Encoder with R=2/3

2.1 Turbo Encoder with coding rate R=2m/(2m+2) for MQAM (M≥16) or R=1/2 for 4QAM

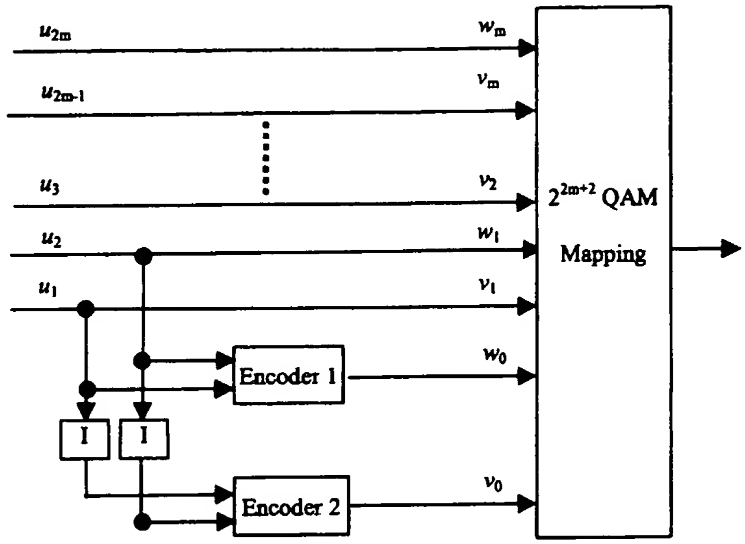

Figure 2. The turbo TCM encoder for rate 2m/(2m+2), m>0.

2.2 Turbo Encoder with coding rate R=(2m+1)/(2m+2) for MQAM (M≥16)

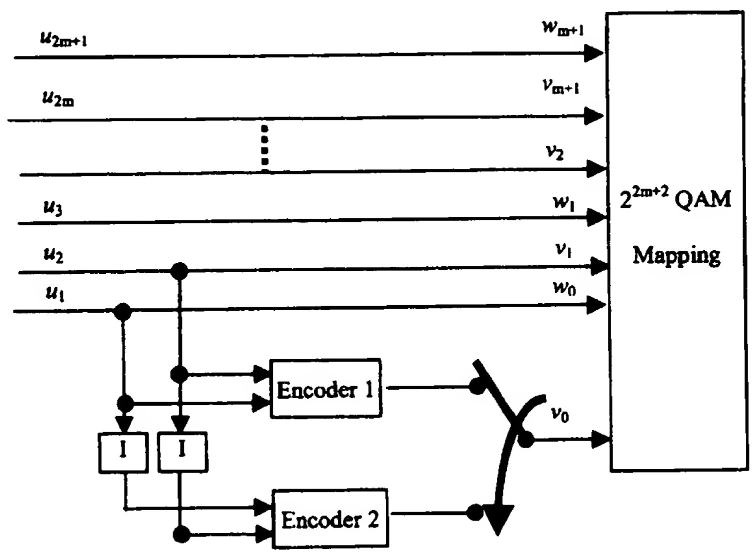

Figure 3. The turbo TCM encoder for rate (2m+1)/(2m+2), m>0.

2.3 An Universal Implementation of Turbo TCM Encoder for MQAM

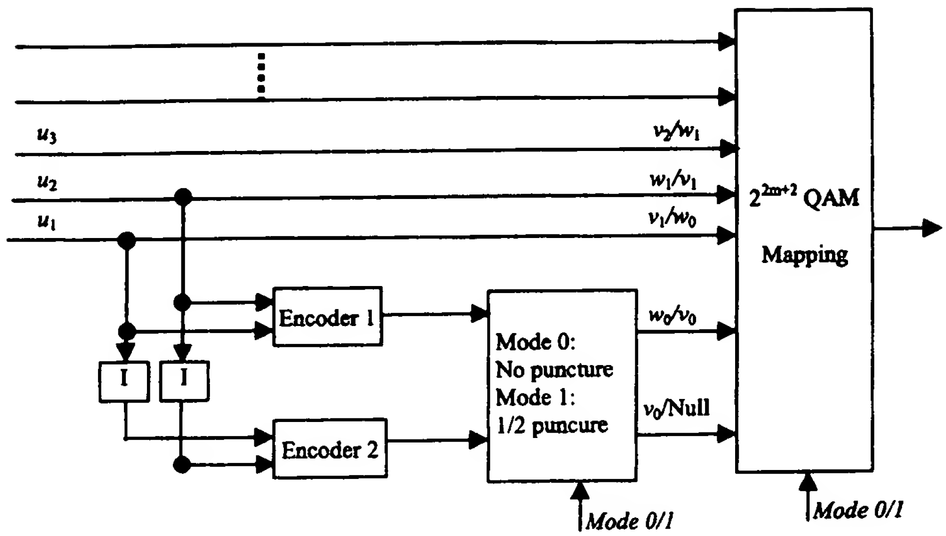

Figure 4. An universal implementation of turbo TCM.

A Coded TCM Scheme with Low Decoding Complexity using Turbo codes/Turbo Product Codes/Low Density Parity Check Codes

Abstract: Here we want to point out that our proposed cocded TCM scheme [1] can also use turbo product codes or low density parity check codes as component codes instead of the turbo codes.

1. A Coded TCM Scheme using Turbo Codes

In [1], we proposed a coded TCM scheme using turbo codes [2]. The coding rate can be $R=2m/(2m+2)$ *or* $R=2m/(2m+1)$ as shown in Fig.1-Fig.2. An universal implementation is also proposed as shown in Fig. 3.

2. A Coded TCM Scheme using Turbo Product Codes (TPC) or Low Density Parity Check (LDPC) Codes

In this paper, we want to point out that the turbo product codes and low density parity check codes [3] can also be used in our scheme [1], as shown in Fig.4-Fig.6.

References:

[1] "A Turbo TCM Scheme with Very Low Decoding Complexity", ITU standard contribution, BI-090R1, Bangalore, India, Oct. 23-27, 2000.

[2] C. Berrou, and A. Glavieux, "Near Optimum Error Correcting Coding And Decoding: Turbo-Codes", IEEE Trans. Commun., vol. COM-44, No. 10, October 1996, pp.1261-1271.

[3] R. G. Gallager, "Low Density Parity Check Codes," IRE Trans. Inform. Theory, vol. IT-8, pp. 21-28, Jan. 1962.

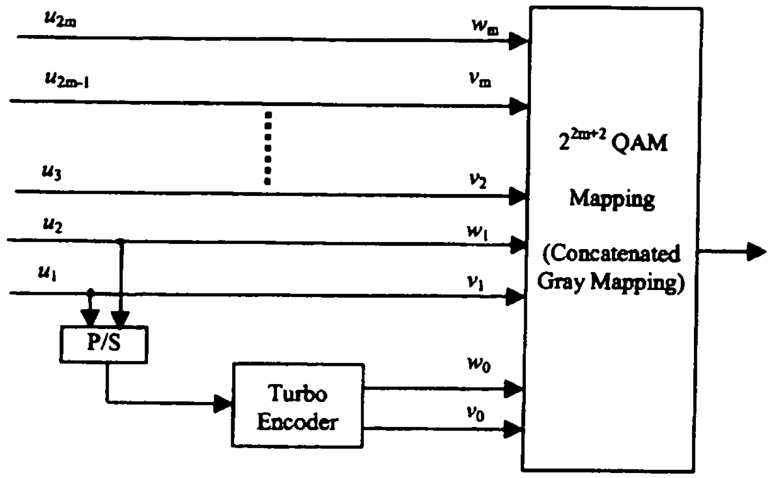

Figure 1. The turbo TCM encoder for rate 2m/(2m+2), m>0.

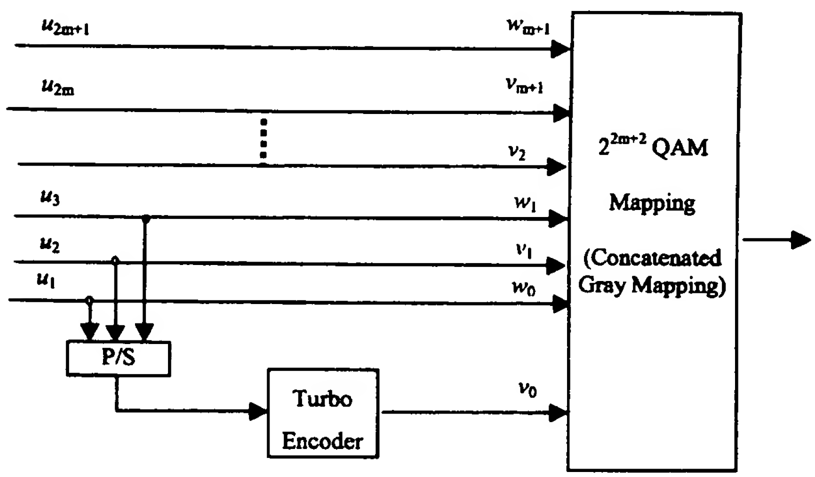

Figure 2. The turbo TCM encoder for rate (2m+1)/(2m+2), m>0.

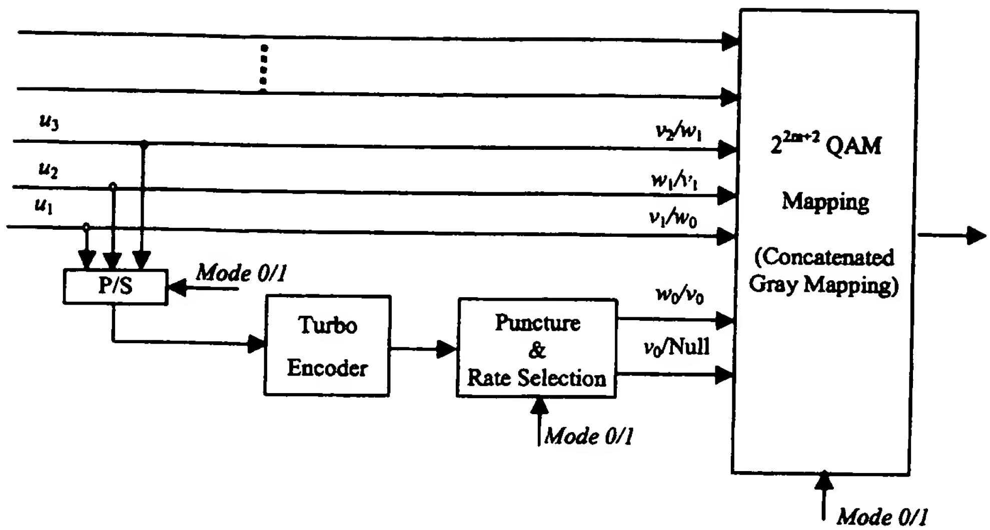

Figure 3. An universal implementation of turbo TCM.

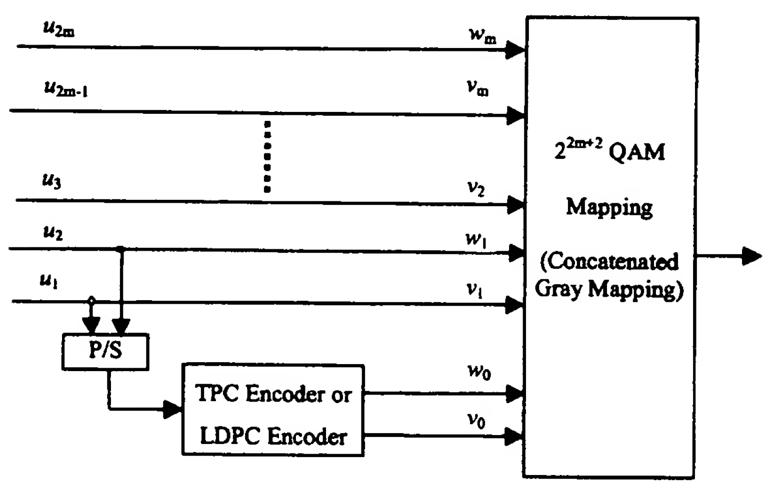

Figure 4. The turbo product coded (TPC) or low density parity check coded (LDPC) TCM encoder for rate 2m/(2m+2), m>0.

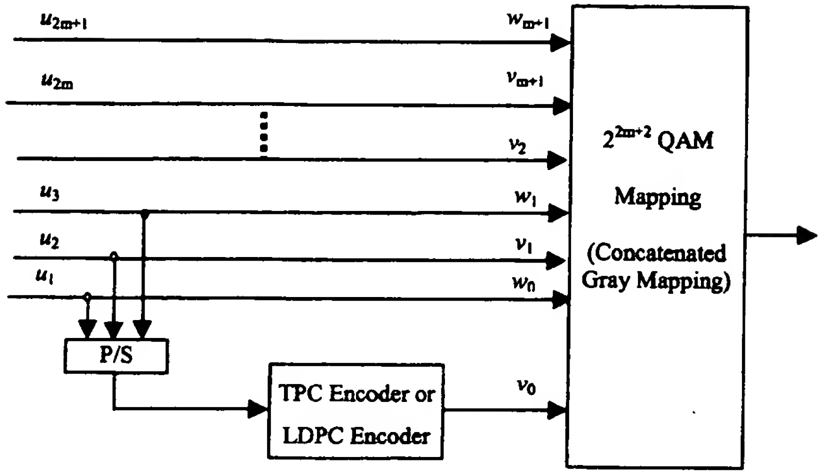

Figure 5. The turbo product coded (TPC) or low density parity check coded (LDPC) TCM encoder for rate (2m+1)/(2m+2), m>0.

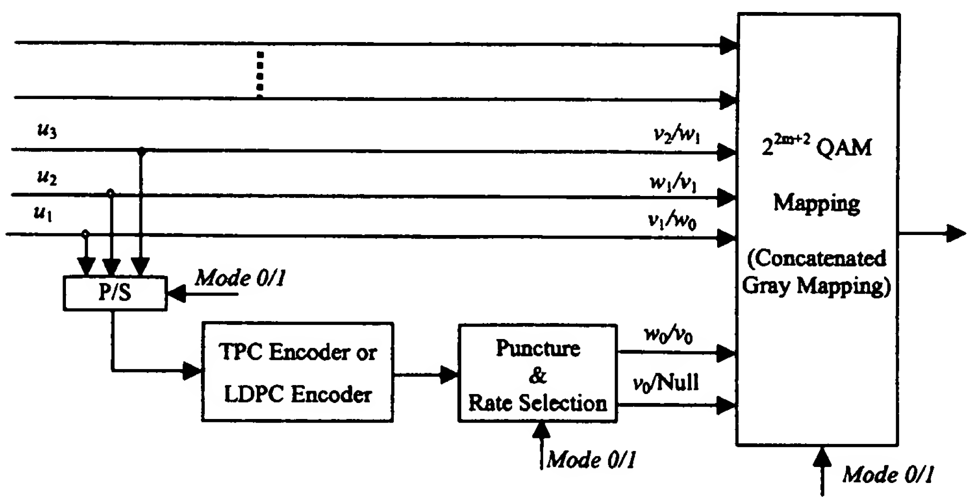

Figure 6. An universal implementation of turbo product coded (TPC) or low density parity check coded (LPDC) TCM encoder.